A&A 455, 11–19 (2006)
DOI: 10.1051/0004-6361:20065111

Astronomy & Astrophysics

Unveiling the nature of *INTEGRAL* objects through optical spectroscopy

IV. A study of six new hard X-ray sources⋆

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Received 28 February 2006 / Accepted 21 April 2006

ABSTRACT

We present further results from our onging optical spectrophotometric campaign at the Astronomical Observatory of Bologna in Loiano (Italy) on unidentified hard X-ray sources detected by *INTEGRAL*. We observed spectroscopically the putative optical counterparts of the *INTEGRAL* sources IGR J00234+6141, IGR J01583+6713, IGR J06074+2205, IGR J13091+1137 and IGR J20286+2544. We find that the first two are Galactic objects, namely a Cataclysmic Variable at a distance $d \sim 300$ pc and a Be/X transient High-Mass X-ray Binary (HMXB) located at ~6.4 kpc, respectively, whereas the last one is identified with MCG +04-48-002, a Starburst/H II galaxy at redshift $z = 0.013$ hiding a Seyfert 2 nucleus. We identify IGR J13091+1137 as the (likely Seyfert 2 type) active nucleus of galaxy NGC 4992, which we classify as an X-ray Bright, Optically Normal Galaxy; this is the first example of this type of object to be detected by *INTEGRAL*, and one of the closest of this class. We moreover confirm the possible Be/X nature of IGR J06074+2205, and we estimate it to be at a distance of ~1 kpc. We also reexamine the spectrum of the $z = 0.087$ elliptical radio galaxy PKS 0352−686, the possible counterpart of the *INTEGRAL* source IGR J03532−6829, and we find that it is a BL Lac. Physical parameters for these sources are also evaluated by discussing our findings in the context of the available multiwavelength information. These identifications further stress the importance of *INTEGRAL* in the study of the hard X-ray spectrum of Active Galactic Nuclei, HMXBs and Cataclysmic Variables.

Key words. galaxies: Seyfert – galaxies: BL Lacertae objects: individual: PKS 0352−686 – stars: novae, cataclysmic variables – X-rays: binaries – techniques: spectroscopic – X-rays: general

1. Introduction

Since its launch in October 2002, the *INTEGRAL* satellite (Winkler et al. 2003) is revolutionizing our knowledge of the hard X-ray sky above 20 keV in terms of both sensitivity and positional accuracy of the detected hard X-ray sources. Indeed, thanks to the capabilities of the ISGRI detector of the instrument IBIS (Ubertini et al. 2003), *INTEGRAL* is able to detect hard X-ray objects at the mCrab level with a typical localization accuracy of 2–3′ (Gros et al. 2003). This has made it possible, for the first time, to obtain all-sky maps in the 20–100 keV range with arcminute accuracy and down to mCrab sensitivities (e.g., Bird et al. 2004, 2006).

Most of the sources in these surveys are known Galactic X-ray binaries (~50%); however, a non-negligible fraction consists of background Active Galactic Nuclei (AGNs; ~10%) and Cataclysmic Variables (CVs; ~5%). A large part of the remaining objects (about one quarter of the sample) has no obvious counterpart at other wavelengths and therefore cannot immediately be associated with any known class of high-energy emitting objects.

However, it should be noted that, although circumstantial evidence was found (Dean et al. 2005) that most of these unknown objects are likely High-Mass X-ray Binaries (HMXBs), optical spectroscopy demonstrates that about half of them are AGNs (Masetti et al. 2004, 2006a,b; hereafter Papers I, II and III). Besides, despite the fact that substantial hard X-ray emission from CVs is not observed in general (e.g., de Martino et al. 2004, and references therein), *INTEGRAL* has already proved its capability to detect this kind of source (e.g., Masetti et al. 2005, 2006c).

In our continuing effort to identify unknown *INTEGRAL* sources (see Papers I–III), we selected a further sample of five objects for which bright candidates could be pinpointed on the basis of their association with sources at other wavebands,

⋆ Based on observations collected at the Astronomical Observatory of Bologna in Loiano (Italy) and with the 2.2 m ESO/MPG telescope of the European Southern Observatory in La Silla (Chile).

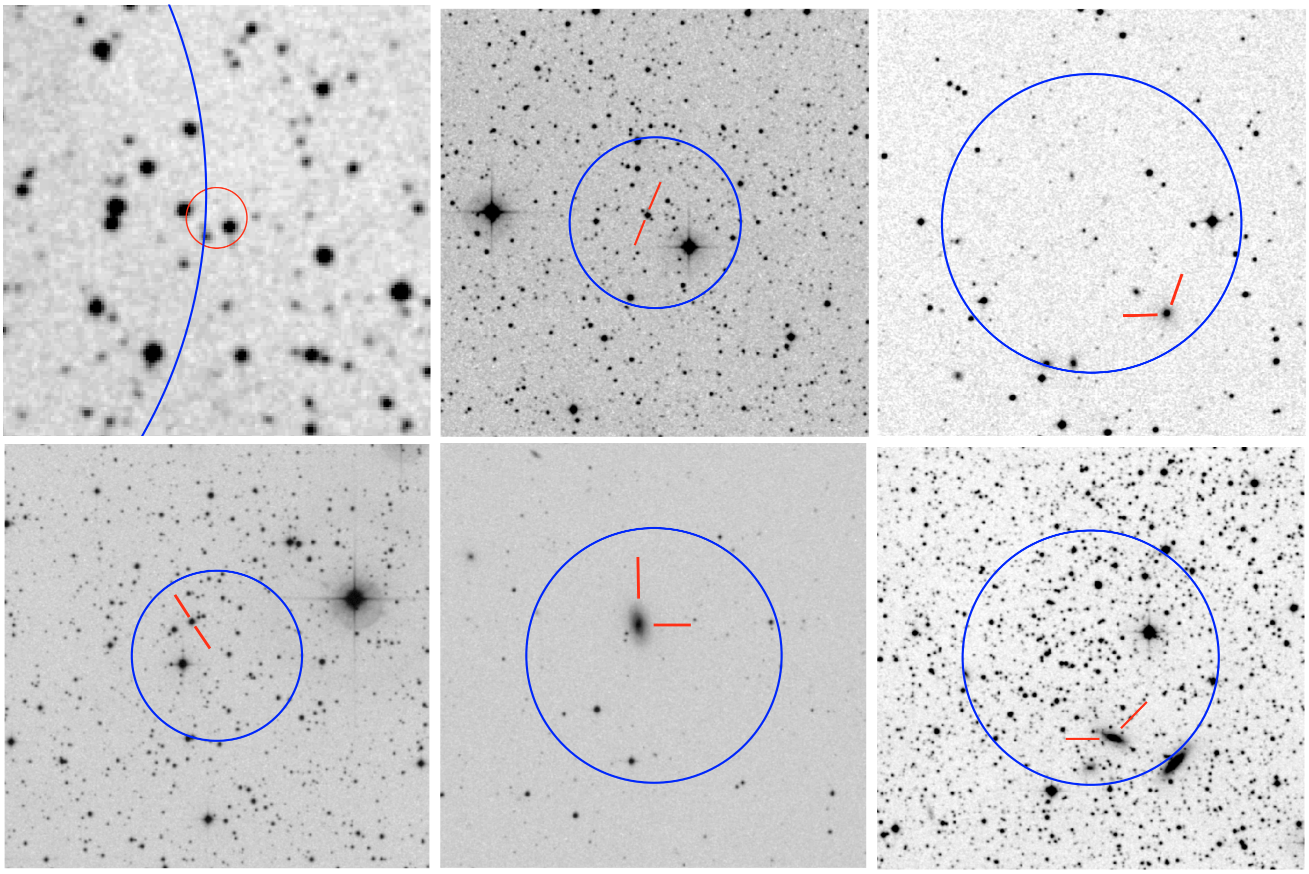

Fig. 1. DSS-II-Red optical images of the fields of IGR J00234+6141 (*upper left panel*), IGR J01583+6713 (*upper middle panel*), IGR J03532−6829 (*upper right panel*), IGR J06074+2205 (*lower left panel*), IGR J13091+1137 (*lower middle panel*) and IGR J20286+2544 (*lower right panel*). In the upper left panel, the small circle indicates the *ROSAT* error box of the soft X-ray source 1RXS J002258.3+614111, whereas the larger curve indicates a portion of the *INTEGRAL* error circle. In the other panels, within the *INTEGRAL* error circles, the putative optical counterparts of IGR J01583+6713 and IGR J06074+2205, as well as the galaxies PKS 0352−686, NGC 4992 and MCG +04-48-002, putative optical counterparts of IGR J03532−6829, IGR J13091+1137 and IGR J20286+2544, respectively, are indicated with tick marks. In the lower right panel, southwest of the galaxy MCG +04-48-002, just outside the *INTEGRAL* error box, the galaxy NGC 6921 is present. Field sizes are $2\farcm5 \times 2\farcm5$ for IGR J00234+6141 and $10' \times 10'$ for the other objects. In all cases, North is up and East to the left.

mainly in soft X-rays and radio. In one more case we considered, as a putative counterpart, a bright emission-line star within the ISGRI error circle. For the caveats regarding this latter choice, we refer the reader to Paper III.

We present here the spectroscopic results obtained at the 1.5-m "G. D. Cassini" telescope of the Astronomical Observatory of Bologna on five of the selected sources, and we reexamine the optical spectroscopic data of the radio galaxy PKS 0352−686 acquired at ESO-La Silla (Chile) with the 2.2 m ESO/MPG telescope. In Sect. 2 we introduce the sample of objects chosen for this observational campaign, while in Sect. 3 a description of the observations is given; Sect. 4 reports and discusses the results for each source. Conclusions are drawn in Sect. 5.

In the following, when not explicitly stated otherwise, we will assume a Crab-like spectrum for our X-ray flux estimates, whereas for the *INTEGRAL* error boxes a conservative 90% confidence level will be considered. When not mentioned, an *INTEGRAL* error box radius of $3'$ is assumed.

2. The selected sources

IGR J00234+6141. This weak hard X-ray source was detected by ISGRI during a 1.6-Ms exposure centered on the Cassiopeia region of the Galaxy; the source flux is 0.72 ± 0.12 mCrab in the 20–50 keV energy band, and 1.4 ± 0.3 mCrab in the 50–100 keV band (den Hartog et al. 2006). These authors suggest that, given that the source lies on the Galactic Plane ($b = -1\fdg0$) and lacks a radio counterpart, it may be an X-ray binary.

The *INTEGRAL* source position reported by den Hartog et al. (2006) is RA = $00^h23^m24^s$ and Dec = $+61°41'32''$ (J2000). At the border of the *INTEGRAL* error box, and marginally consistent with it, is the bright *ROSAT* X-ray source 1RXS J002258.3+614111 (Voges et al. 1999) with a 0.1–2.4 keV flux of $(4.7 \pm 0.9) \times 10^{-13}$ erg cm^{-2} s^{-1}. According to the findings of Stephen et al. (2005, 2006), this indicates that the source is the soft X-ray counterpart of IGR J00234+6141. Within the $11''$ *ROSAT* error box (Fig. 1, upper left panel), at least 6 objects can be seen on the DSS-II-Red Survey[1]; the two brightest optical sources have magnitudes $B \sim 16.6$ and $R \sim 16.3$ (the westernmost one), and $B \sim 17.2$ and $R \sim 16.5$ (the easternmost one) according to the USNO-A2.0[2] catalogue. We acquired spectra of each of these two objects to see whether

[1] Available at `http://archive.eso.org/dss/dss/`
[2] Available at
`http://archive.eso.org/skycat/servers/usnoa`

either may be responsible for the hard X-ray emission detected by *INTEGRAL*.

Preliminary spectroscopic results on the possible counterpart of this source were already reported by Halpern & Mirabal (2006) and Bikmaev et al. (2006), and are based on more recent spectroscopic observations compared to those shown in the present paper.

IGR J01583+6713. This new hard X-ray transient was discovered (Steiner et al. 2005) in early December 2005 with ISGRI, at coordinates (J2000) RA = $01^h58^m17^s$, Dec = $+67°13'12''$, with an uncertainty of $2'$. The flux at the time of the discovery was ~14 mCrab in the 20–40 keV band, declining in the days following the discovery. The source was not detected down to a flux limit of 7 mCrab in the 40–80 keV band.

Pointed follow-up *Swift*/XRT observations of the field allowed the detection of the soft X-ray counterpart of IGR J01583+6713, at RA = $01^h58^m18\overset{s}{.}2$, Dec = $+67°13'25\overset{''}{.}9$ (J2000; Kennea et al. 2005). This localization with arcsecond precision allowed these authors to propose a single, relatively bright optical object lying within the *Swift*/XRT error box as the counterpart to this *INTEGRAL* source. This object (Fig. 1, upper middle panel) has magnitudes B = 14.98, R = 13.25, I = 12.12 (Monet et al. 2003).

Spectral fitting of *Swift*/XRT data of this source (Kennea et al. 2005) indicates a 0.2–10 keV flux of 1.5×10^{-11} erg cm^{-2} s^{-1} and suggests the presence of a large neutral hydrogen column density, as high as 10^{23} cm^{-2}, larger than the Galactic value in the direction of IGR J01583+6713.

The optical spectroscopic follow-up of Halpern & Tyagi (2005a) confirmed that this object is the counterpart of IGR J01583+6713 and classified the source as a Be/X-ray binary. In this case also, the identification was obtained through more recent spectroscopy compared to that presented here.

IGR J03532−6829. This object was detected in the *INTEGRAL* Large Magellanic Cloud survey of Götz et al. (2006), with coordinates (J2000) RA = $03^h53^m14^s$ and Dec = $-68°29'00''$ (J2000) and a 20–40 keV flux of 0.6 mCrab. A *ROSAT* bright soft X-ray source (1RXS J035257.7−683120; Voges et al. 1999) and a SUMSS radio object (SUMSS J035257−683118; Mauch et al. 2003) were found within the $3\overset{'}{.}5$-radius ISGRI error box. Their positional errors were consistent with them being the same source. This object has an X-ray flux of $(3.2 \pm 0.5) \times 10^{-12}$ erg cm^{-2} s^{-1} in the 0.1–2.4 keV band and a radio flux density of 390.8 ± 11.8 mJy at 843 MHz. X-ray emission consistent with this position was also detected by *Einstein* (Elvis et al. 1992) and by *RXTE* (Revnivtsev et al. 2004), with fluxes $(9.0 \pm 2.2) \times 10^{-12}$ erg cm^{-2} s^{-1} and $(6.8 \pm 1.3) \times 10^{-12}$ erg cm^{-2} s^{-1} in the 0.16–3.5 keV and 3–8 keV bands, respectively.

The radio and soft X-ray arcsecond-sized error boxes are coincident with the body of an elliptical galaxy (see Fig. 1, upper right panel) characterized by the flat-spectrum radio source PKS 0352−686 (Wright et al. 1994). The galaxy has USNO-A2.0 optical magnitudes B ~ 13.6 and R ~ 12.5. According to the optical survey of Fischer et al. (1998), this galaxy has redshift z = 0.087 and may be part of a cluster responsible for the X-ray emission, even if a BL Lac nature cannot be excluded. We thus performed a further analysis of the data reported by Fischer et al. (1998) on this object to try to ascertain its actual nature.

IGR J06074+2205. This transient source was discovered by *INTEGRAL*'s JEM-X telescopes and ISGRI instrument at coordinates (J2000) RA = $06^h07\overset{m}{.}4$, Dec = $+22°05'$ (error radius: $2'$) between 15 and 16 February 2003 during an observation of the Crab region (Chenevez et al. 2004). According to these authors, the source had fluxes of 7 ± 2 mCrab (3–10 keV) and ~15 mCrab (10–20 keV) at the time of the discovery.

Recent (27 December 2005) optical spectroscopic observations of stars in the source error box show the presence of a Be star (Fig. 1, lower left panel) at RA = $06^h07^m26\overset{s}{.}6$, Dec = $+22°05'48''$ with H$_\alpha$ emission (Halpern & Tyagi 2005b). These authors suggest that this is the counterpart of IGR J06074+2205 and that the radio source reported by Pooley (2004) within the *INTEGRAL* error circle is an unrelated object. We made detailed spectroscopic observations of the Be star to deepen the optical study of this object.

IGR J13091+1137. This is one of the 8 objects included in the *INTEGRAL*/*Chandra* minisurvey of Sazonov et al. (2005), with ISGRI coordinates RA = $13^h09^m04\overset{s}{.}1$, Dec = $+11°37'19''$ (J2000). These authors report that this source has 0.5–8 keV and 17–60 keV fluxes of $(1.2 \pm 0.2) \times 10^{-12}$ erg cm^{-2} s^{-1} and $(3.4 \pm 0.5) \times 10^{-11}$ erg cm^{-2} s^{-1}, respectively, and a large neutral hydrogen column density, $N_H = (90 \pm 10) \times 10^{22}$ cm^{-2}, along the line of sight.

The subarcsecond *Chandra* position, RA = $13^h09^m05\overset{s}{.}60$, Dec = $+11°38'02\overset{''}{.}9$ (J2000; error radius: ~$0\overset{''}{.}6$) falls on the nucleus of the bright Sa-type spiral galaxy NGC 4992 (in Fig. 1, lower middle panel; see also Halpern 2005; and Sazonov et al. 2005). This galaxy has total magnitude B ~ 14.5 and lies at redshift z = 0.0251 ± 0.0002 (Prugniel 2006). The nucleus of this galaxy is also a radio source, FIRST J130905.5+113803, with 1.4 GHz flux density of 2.01 ± 0.15 mJy (Becker et al. 1997). Sazonov et al. (2005) thus suggested that this object is most likely an AGN, but no clearer indication on the actual nature of this source is reported by these authors.

Preliminary results on our spectroscopic optical study of this source were given in Masetti et al. (2006d).

IGR J20286+2544. This source appears in the *INTEGRAL* AGN catalogue of Bassani et al. (2006), at coordinates (J2000) RA = $20^h28^m37\overset{s}{.}4$ and Dec = $+25°45'54''$ (J2000) with a 20–100 keV flux of 2.42 ± 0.42 mCrab. One single radio source, with flux density 27.4 ± 1.2 mJy at 1.4 GHz (Condon et al. 1998), is present in the X-ray error box. Coincident with this radio source, a relatively bright (B ~ 15.4 mag) and close (z = 0.0142 ± 0.0002) galaxy, MCG +04-48-002, is found (Paturel et al. 2003; see Fig. 1, lower right panel). This object is also a bright IRAS far-infrared (FIR) galaxy (Sanders et al. 2003).

It should however be noted that, just outside the *INTEGRAL* error circle, a further NVSS source at a 1.4 GHz flux density of 84.8 ± 3.1 mJy is detected (Condon et al. 1998) positionally coincident with the B ~ 14.4 mag galaxy NGC 6921, lying at redshift z = 0.0147 ± 0.0007 (Paturel et al. 2003).

Neither of these galaxies was detected by *ROSAT* in the 0.1–2.4 keV band. However, an analysis of archival *Swift*/XRT data (Obs. ID: 00035276001; Landi et al., in preparation) shows that both objects are X-ray emitting in the 0.1–10 keV band. The arcsec-sized XRT error boxes clearly mark the nuclei of these galaxies as the sites of the detected X-ray emissions, with the nucleus of MCG +04-48-002 being about 10 times brighter than that of NGC 6921 in this X-ray range. Thus, given the position inside the *INTEGRAL* error circle and the X-ray intensity, MCG +04-48-002 is the best optical counterpart candidate of IGR J20286+2544. Nevertheless, optical spectroscopy is the optimal medium to tell which of the two galaxies is the responsible for the hard X-ray emission.

Table 1. Log of the spectroscopic observations presented in this paper.

Object	Date	Telescope	Mid-exposure time (UT)	Grism number	Slit (arcsec)	Exposure time (s)
IGR J00234+6141	01 Oct. 2005	1.5 m Loiano	18:41:21	#4	2.0	2×1800
IGR J01583+6713	23 Dec. 2005	1.5 m Loiano	17:41:25	#4	2.0	2×1200
IGR J03532−6829 (=PKS 0352−686)	05 Oct. 1994	2.2 m ESO/MPG	09:17:27	#1	1.5	900
IGR J06074+2205	06 Feb. 2006	1.5 m Loiano	19:15:18	#4	2.0	2×1200
IGR J13091+1137 (=NGC 4992)	01 Feb. 2006	1.5 m Loiano	03:01:56	#4	2.0	900
MCG +04-48-002	01 Oct. 2005	1.5 m Loiano	22:24:20	#4	2.0	2×1200
NGC 6921	18 Oct. 2005	1.5 m Loiano	23:06:47	#4	2.0	900

3. Optical spectroscopy

The Bologna Astronomical Observatory 1.52-m "G. D. Cassini" telescope equipped with BFOSC was used to make spectroscopic observations of the two brighter objects within the *ROSAT* error box of X-ray source 1RXS J002258.3+614111, the putative optical counterparts of IGR J01583+6713 and IGR J06074+2205, and galaxies NGC 4992, MCG +04-48-002 and NGC 6921 (see Fig. 1). The BFOSC instrument uses a 1300×1340 pixel EEV CCD. In all observations, Grism #4 and a slit width of 2″ were used, providing a 3500–8700 Å nominal spectral coverage. The use of this setup secured a final dispersion of 4.0 Å/pix for all spectra. The spectra of the putative counterparts of 1RXS J002258.3+614111 were acquired with the slit rotated northwards by 25° from its original E-W position in order to include both objects at once. The complete log of the observations is reported in Table 1.

After cosmic-ray rejection, the spectra were reduced, background subtracted and optimally extracted (Horne 1986) using IRAF[3]. Wavelength calibration was performed using He-Ar lamps acquired soon after each spectroscopic exposure; all spectra were then flux-calibrated using the spectrophotometric standard BD+25°3941 (Stone 1977). Finally, and when applicable, different spectra of the same object were stacked together to increase the S/N ratio. The wavelength calibration uncertainty was ~0.5 Å for all cases; this was checked using the positions of background night sky lines.

Details on the spectroscopic observation concerning PKS 0532−686 secured with the 2.2 m ESO/MPG telescope plus EFOSC, and on the corresponding data reduction, are reported in Table 1 and in Fischer et al. (1998).

4. Results and discussion

Table 2 reports the (observer's frame) wavelengths, fluxes and equivalent widths (*EW*s) of the main emission lines present in each spectrum displayed in Figs. 2 and 3. The line fluxes from the extragalactic sources NGC 4992, MCG +04-48-002 and NGC 6921 were dereddened for Galactic absorption along their line of sight assuming color excesses $E(B-V) = 0.026$ mag for the first and $E(B-V) = 0.44$ mag for the other two, following the prescription of Schlegel et al. (1998) and assuming the Galactic extinction law of Cardelli et al. (1989). The spectra of these galaxies were not corrected for starlight contamination (see, e.g., Ho et al. 1993, 1997) given their limited S/N and resolution. We do not consider this to affect any of our conclusions. In the following we assume a cosmology with $H_0 = 65$ km s^{-1} Mpc^{-1}, $\Omega_\Lambda = 0.7$ and $\Omega_m = 0.3$.

4.1. IGR J00234+6141

The westernmost of the two brightest putative counterparts of IGR J00234+6141 within the *ROSAT* error box can be discounted from being the counterpart of this hard X-ray source as its optical spectrum shows the typical absorption features of a normal late F-/early G-type star with no specific peculiarity at all.

The other, eastward, object shows an optical spectrum with a host of narrow emission lines at redshift $z = 0$ superimposed on a blue continuum. In particular, all of the Balmer series up to at least H_η, He I and He II, the C III + N II Bowen blend, and other lines which we identified as O I and Fe I, are observed in emission (see Fig. 2, upper left panel). These spectral features are typical of a CV (e.g., Warner 1995) and are consistent with the independent subsequent findings of Halpern & Mirabal (2006) derived from spectroscopy taken on 2006 January 24, and the Bikmaev et al.'s (2006) analysis of their 2005 October 8–9 spectra.

The fact that we see the object at roughly the same optical level of the DSS-II-Red image suggests that it was at quiescence during our observation. Moreover, the He II line detection is suggestive of a magnetic nature for this CV (e.g., Warner 1995), although this does not conclusively prove it.

Although this object lies nominally just outside of the 90% *INTEGRAL* error circle, and it is therefore only marginally consistent with the hard X-ray position, its optical spectrum, together with the positional correlation with a bright *ROSAT* source (see Stephen et al. 2005, 2006), strongly indicates that this is the optical counterpart of IGR J00234+6141.

Assuming an intrinsic H_α/H_β line ratio of 2.86 (Osterbrock 1989), the observed value (~2) indicates that negligible absorption is present along the line of sight to this source; this means that the object should be relatively close to Earth. Assuming an absolute magnitude $M_V \sim 9$ and an intrinsic color index $(V-R)_0 \sim 0$ mag (Warner 1995) we can give an estimate for the distance to IGR J00234+6141. With an optical magnitude $R \sim 16.3$ and no substantial further absorption along the line of sight, we determine that $d \sim 300$ pc.

Using this distance estimate, we obtain 0.1–2.4 keV and 20–100 keV X-ray luminosities of 4.7×10^{30} erg s^{-1} and 1.7×10^{32} erg s^{-1} for IGR J00234+6141. These values are on the fainter side of the X-ray luminosity distribution for high-energy emitting intermediate polar (IP) CVs (see de Martino et al. 2004; and Suleimanov et al. 2005).

[3] IRAF is the Image Reduction and Analysis Facility made available to the astronomical community by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under contract with the US National Science Foundation. It is available at `http://iraf.noao.edu/`

Table 2. Observer's frame wavelengths, *EW*s (both in Ångstroms) and fluxes (in units of 10^{-15} erg s^{-1} cm^{-2}) of the main emission lines detected in the spectra of the objects reported in Figs. 2 and 3. For NGC 4992, MCG +04-48-002 and NGC 6921 the values are corrected for Galactic reddening assuming a color excess $E(B-V) = 0.026$ mag for the former one and $E(B-V) = 0.44$ mag for the latter two (from Schlegel et al. 1998). The error on the line positions is conservatively assumed to be ±4 Å, i.e., comparable with the spectral dispersion (see text).

Line	$\lambda_{\rm obs}$ (Å)	$EW_{\rm obs}$ (Å)	Flux
IGR J00234+6141			
H_δ	4098	7.0 ± 0.7	5.6 ± 0.6
Fe I λ4264	4264	3.0 ± 0.5	2.2 ± 0.3
H_γ	4339	8.6 ± 0.6	6.4 ± 0.4
He I λ4471	4469	2.1 ± 0.4	1.5 ± 0.3
He II λ4686	4687	8.1 ± 0.6	5.4 ± 0.4
H_β	4861	13.8 ± 0.7	8.7 ± 0.4
Fe I λ5769	5679	3.0 ± 0.3	1.73 ± 0.17
He I λ5875	5870	5.5 ± 0.4	3.1 ± 0.2
H_α	6559	37.1 ± 1.1	18.4 ± 0.6
He I λ6678	6674	4.3 ± 0.4	2.1 ± 0.2
He I λ7065	7063	1.8 ± 0.2	0.82 ± 0.12
Fe I λ7131	7131	1.1 ± 0.2	0.5 ± 0.1
O I λ8428	8430	4.1 ± 0.8	1.5 ± 0.3
IGR J01583+6713			
H_β	4864	6.4 ± 0.4	10.1 ± 0.7
H_α	6563	74 ± 2	216 ± 7
IGR J06074+2205			
H_α	6560	8.3 ± 0.6	60 ± 4
IGR J13091+1137			
[O III] λ5007	5132	1.5 ± 0.5	1.7 ± 0.5
[N II] λ6548	6690	0.9 ± 0.3	1.0 ± 0.3
H_α	6712	1.8 ± 0.6	1.9 ± 0.6
[N II] λ6583	6746	3.2 ± 0.3	3.4 ± 0.3
IGR J20286+2544 (=MCG +04-48-002)			
H_β	4927	6.9 ± 0.7	10.5 ± 1.1
[O III] λ4958	5023	4.9 ± 0.7	7.5 ± 1.1
[O III] λ5007	5072	9.4 ± 0.9	14.8 ± 1.5
[N II] λ6548	6634	6.5 ± 0.6	8.8 ± 0.9
H_α	6652	61 ± 3	108 ± 5
[N II] λ6583	6673	25.4 ± 1.3	44 ± 2
[S II] λ6716	6808	12.1 ± 0.8	22.3 ± 1.6
[S II] λ6731	6823	7.9 ± 0.6	12.9 ± 0.9
NGC 6921			
[N II] λ6583	6679	3.2 ± 0.3	27 ± 3
[S II] λ6716	6815	0.35 ± 0.05	2.9 ± 0.4
[S II] λ6731	6825	1.18 ± 0.18	9.8 ± 1.5

4.2. IGR J01583+6713

As one can see in Fig. 2, upper right panel, the optical spectrum of IGR J01583+6713 is characterized by an almost featureless reddened continuum dominated by a strong and single-peaked narrow H_α emission with $EW = 74 \pm 2$ Å. Further spectral characteristics are a weaker H_β emission line ($EW = 6.4 \pm 0.4$ Å), along with the Na doublet at 5890 Å and diffuse interstellar bands in absorption. All features are consistent with redshift zero, indicating that this is a Galactic source. These results are comparable to those reported by Halpern & Tyagi (2005a) from a spectrum acquired one day after ours, and independently confirm the presence of absorption detected in the X-ray data (Kennea et al. 2005).

Confirmation of the presence of reddening comes from the observed H_α/H_β line ratio (21.4 ± 1.6). This, following Osterbrock (1989) implies a color excess $E(B-V) = 2.04$. It should be noted, however, that if we correct the magnitudes of the optical counterpart using this color excess, we obtain corrected color indices which are too blue and which do not match with those of any known spectral type (Lang 1992). We thus consider the Galactic color excess measure along the line of sight of IGR J01583+6713, $E(B-V) = 1.41$ mag (Schlegel et al. 1998), a more acceptable estimate. This, in passing, suggests a large distance to the source.

We also note that the assumed reddening estimate implies, from Predehl & Schmitt (1995), a column density of $\sim 1 \times 10^{22}$ cm^{-2}, which is ~10 times lower than that measured from X-ray data. This suggests that further absorption, produced by the material in accretion and local to the X-ray emitting source, is present.

The overall spectral shape strongly indicates that this is a HMXB. However, the lack of detectable stellar absorption lines (mostly due to the substantial absorption along the line of sight of IGR J01583+6713) prevents a secure spectral classification of the companion star. Nevertheless, we can confidently say that a blue supergiant is ruled out due to the large *EW* of H_α (see e.g. the compilation of Leitherer 1988).

Next, using the optical magnitudes for this object and the Galactic color excess value, we find that the star has a dereddened color index $(B-R)_0 = -0.42$. This, according to Wegner (1994), means that the spectral type of the secondary star in the X-ray binary IGR J01583+6713 is either O8 III or O9 V. If we use the absolute magnitudes and color indices of stars as in Lang (1992), these choices imply distances of 11.6 kpc and 6.4 kpc, respectively. We consider the latter as the more viable option because the source has Galactic longitude $l = 129\overset{\circ}{.}4$, and a distance of 11.6 kpc from Earth would place IGR J01583+6713 far outside the Galaxy. Assuming a supergiant companion would move the system further away, thus making this hypothesis even more unlikely.

The cases for a Low Mass X-ray Binary (LMXB) or a CV as the nature of this source are less appealing. Indeed, in the assumption that $(B-R)_0 \sim 0 \sim M_R$ for a LMXB (e.g., van Paradijs & McClintock 1995), one finds a distance of 1.2 kpc for the source. An even more extreme situation is found in the CV case: using the same approach applied to IGR J00234+6141 (see Sect. 4.1), we obtain a distance of 19 pc. Neither distance can explain the large reddening observed in X-rays and optical and, to our knowledge, no known LMXBs or CVs show such a huge H_α emission. Besides, the comparison of the spectrum of IGR J01583+6713 with that of IGR J00234+6141 suggests that they belong to different classes of objects.

Thus, using the above distance estimate of 6.4 kpc, we find that this source had X-ray luminosities of 7.3×10^{34} erg s^{-1} and 5.2×10^{35} erg s^{-1} in the 0.2–10 keV and 20–40 keV bands, respectively, during the active phase. These luminosities are comparable to that of the Be/X HMXB system X Per/4U 0352+309 (e.g., Haberl et al. 1998). Therefore we conclude that IGR J01583+6713 is a transient Be/X HMXB.

4.3. IGR J03532–6829 (=PKS 0352–686)

This object does not show emission lines in its optical spectrum (see Fig. 2, lower left panel): only a few absorption features, such

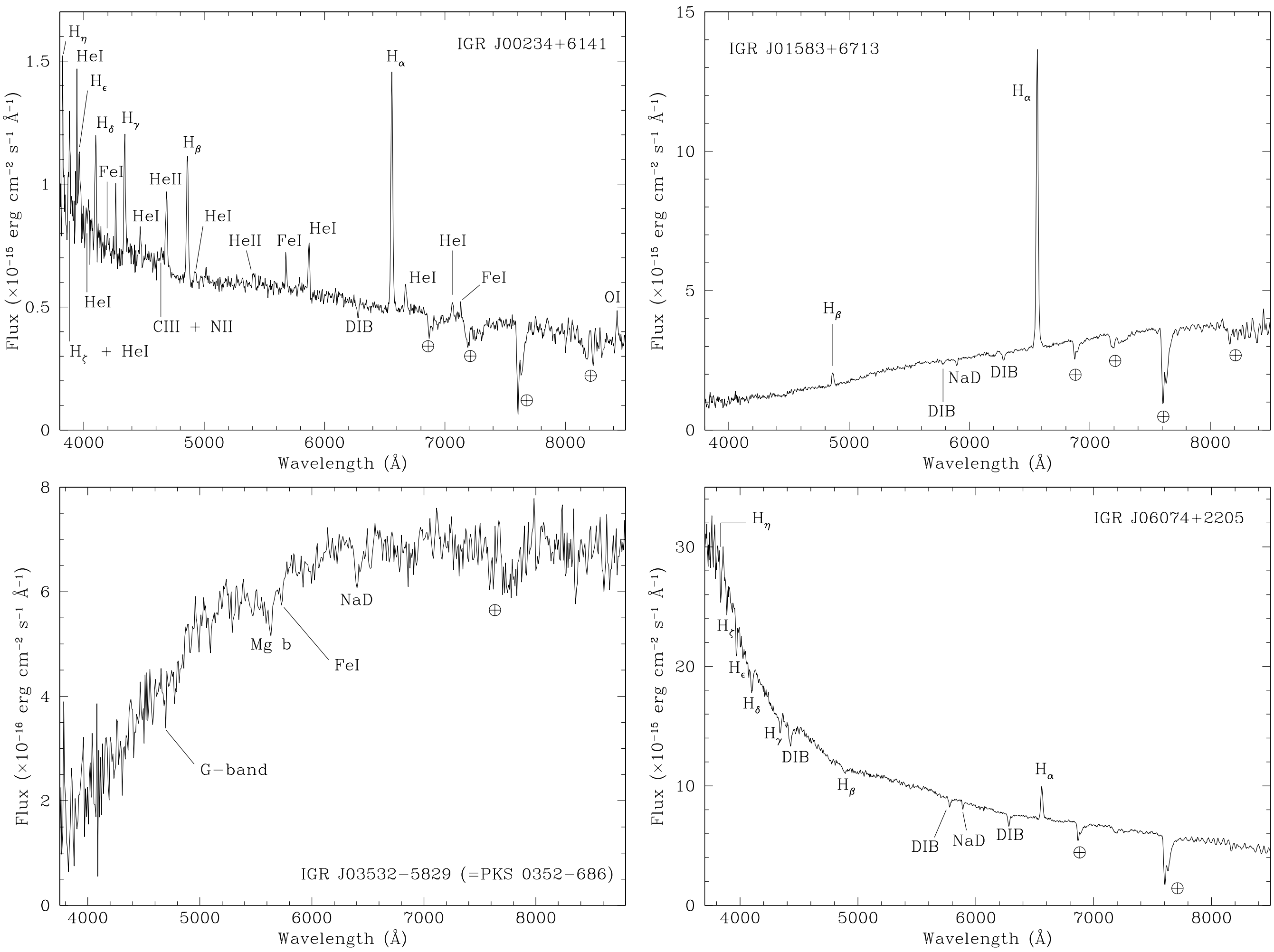

Fig. 2. Spectra (not corrected for the intervening Galactic absorption) of the optical counterparts of IGR J00234+6141 (*upper left panel*), IGR J01583+6713 (*upper right panel*), IGR J06074+2205 (*lower right panel*) acquired with the Cassini telescope at Loiano, and of IGR J03532−6829 (=PKS 0352−686; *lower left panel*) acquired with the 2.2 m ESO/MPG. For each spectrum the main spectral features are labeled. The symbol ⊕ indicates atmospheric telluric absorption bands.

as the G- and Mg b bands at 4304 and 5175 Å, respectively, and the Fe I λ5270 line, are seen with a redshift $z = 0.087 \pm 0.001$, as reported by Fischer et al. (1998).

In order to classify the galaxy, we followed the approach of Laurent-Muehleisen et al. (1998), finding the following relevant information: (1) no emission lines are detected, the upper limit to the *EW* of any emission feature being less than ~5 Å; (2) no significant Balmer absorption lines are detected; (3) the absorption features superimposed on the continuum of PKS 0352−686 have strengths generally consistent with those of other BL Lac objects (see Laurent-Muehleisen et al. 1998); (4) the Ca II break contrast at 4000 Å (Br_{4000}), as defined by Dressler & Shectman (1987), is ~29%, again similar to other BL Lac objects in the sample of Laurent-Muehleisen et al. (1998).

Moreover, according to Fischer et al. (1998), the X-ray emission detected by *ROSAT* does not appear to be extended, and thus is more consistent with being produced by an AGN rather than by heated gas in a cluster. Further, substantial radio emission is detected from the galaxy. By using the radio-to-optical $\alpha_{\rm ro}$ and optical-to-X-ray $\alpha_{\rm ox}$ spectral indices as defined in Laurent-Muehleisen et al. (1999), we get the same indication: indeed, the values of the two parameters above for PKS 0352−686 are ~0.3 and ~1.6, respectively, placing it in the domain of BL Lacs. Taking into account the above information, we are led to classify PKS 0352−686 as a BL Lac object and as the optical counterpart of the hard X-ray source IGR J03532−6829.

The redshift of PKS 0352−686 implies a luminosity distance $d_{\rm L}$ = 428 Mpc to this galaxy. This allows us to compute the 0.1–2.4 keV, 3–8 keV and 20–40 keV luminosities of this source as 7×10^{43} erg s^{-1}, 1.5×10^{44} erg s^{-1} and 1×10^{44} erg s^{-1}, respectively. Analogously, correcting for the Galactic reddening along the PKS 0352−686 line of sight by assuming a color excess $E(B-V) = 0.093$ (Schlegel et al. 1998), we find that the absolute B-band magnitude of this object is $M_B \sim -24.9$. The values above place this object in the high end of the BL Lac luminosity distribution (e.g., Beckmann et al. 2006).

4.4. IGR J06074+2205

In the optical spectrum of the putative counterpart of IGR J06074+2205 (Fig. 2, lower right panel) we confirm the presence of H_α in emission and of other Balmer lines (up to at least H_η) in absorption at redshift $z = 0$. We thus support the conclusions of Halpern & Tyagi (2005b) according to which this is an early-type emission line star and that IGR J06074+2205 is a Galactic HMXB.

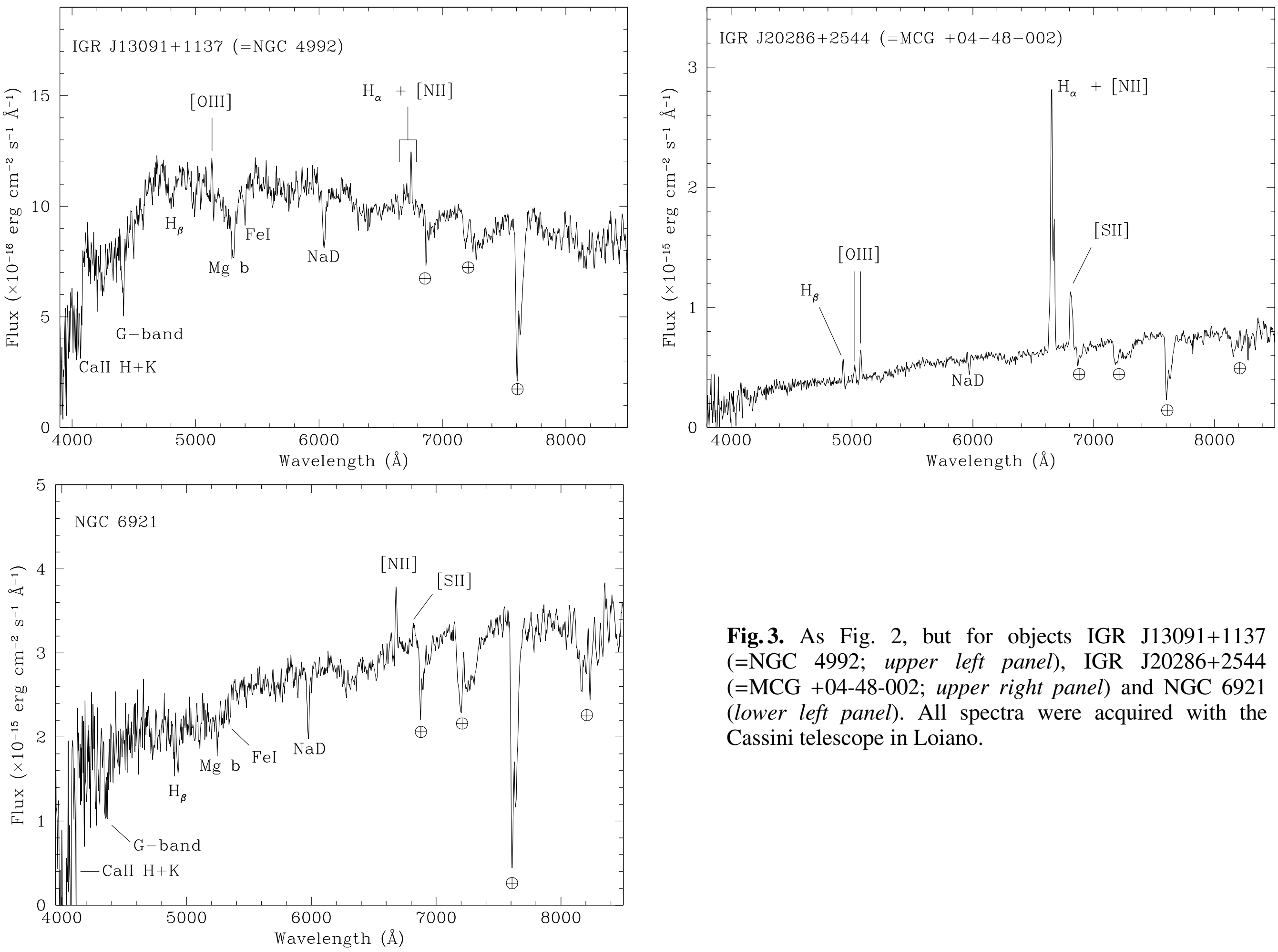

Fig. 3. As Fig. 2, but for objects IGR J13091+1137 (=NGC 4992; *upper left panel*), IGR J20286+2544 (=MCG +04-48-002; *upper right panel*) and NGC 6921 (*lower left panel*). All spectra were acquired with the Cassini telescope in Loiano.

The absence of He II lines and the weakness of He I and light metal absorption lines indicates (following Jaschek & Jaschek 1987) that this star is of late B spectral type. The *EW* of the H_α emission suggests that this is not a supergiant (see Leitherer 1988); moreover, the narrowness of Balmer absorption and the overall similarity with the optical spectrum of HD 100199 and HD 146803 (Paper III) hints that this star may be a giant.

Thus, assuming a spectral type B8 III (which implies $B-R = -0.12$ and $M_B = -1.2$; Wegner 1994; Lang 1992), and using USNO-B1.0 magnitudes $B = 12.70$ and $R = 11.29$ (Monet et al. 2003), we derive a color index $E(B-V) = 1.0$ and a dereddened magnitude $B_0 = 8.9$. This would place the star at $d \sim 1.0$ kpc from Earth, on the near side of the Perseus Arm (Leitch & Vasisht 1998).

This distance implies a 3–20 keV luminosity of 2.5×10^{34} erg s^{-1} for IGR J06074+2205 during outburst, comparable to that of Be/X HMXB transient systems in their active phase (e.g., White et al. 1995). However, for the reasons illustrated in Paper III, we caution the reader that the association between IGR J06074+2205 and this optical emission-line star should still be considered as tentative, albeit likely, until further multiwavelength investigations (e.g., an X-ray observation able to provide an arcsec-sized position of the high-energy source) are available.

4.5. IGR J13091+1137 (=NGC 4992)

Inspection of the optical spectrum of NGC 4992 (Fig. 3, upper left panel) shows the typical features of a spiral galaxy (e.g., Kennicutt 1998), with the CaII H+K doublet, the G-band at 4304 Å, H_β, the 5175 Å Mg b band, the Fe I λ5270 line, and the 5890 Å Na doublet, all in absorption and at a redshift $z = 0.025 \pm 0.001$ (thus consistent with the measurement of Prugniel 2006). Superimposed onto this continuum, and at the same redshift, a few narrow (with full width at half maximum of $\lesssim$600 km s^{-1}) emission lines are detected, the most prominent of which is [N II] λ6583 (see Table 2).

This result, combined with the observed 0.5–8 keV X-ray luminosity (see Sazonov et al. 2005) suggests that NGC 4992 may belong to the class of X-ray Bright, Optically Normal Galaxies (XBONGs; e.g., Comastri et al. 2002). Indeed, the optical spectral results are reminiscent of the sample of XBONGs detected with *XMM-Newton* by Severgnini et al. (2003).

The measured redshift corresponds to a luminosity distance $d_L = 118$ Mpc. This implies X-ray luminosities of 2.0×10^{42} erg s^{-1} and 5.7×10^{43} erg s^{-1} in the 0.5–8 keV and 17–60 keV bands, respectively, average for the luminosity range of typical AGNs (Beckmann et al. 2006).

Although the optical spectrum is not discriminant about the real nature of this source (the observed narrow lines could be associated with the host galaxy, which may completely outshine the AGN), the high X-ray luminosity and the intrinsic absorption measured by *Chandra*, $N_H = (90 \pm 10) \times 10^{22}$ cm^{-2} according to Sazonov et al. (2005), along with the *INTEGRAL* luminosity strongly suggest that the best explanation for the nature of this source is a heavily absorbed AGN. In any case, to conclusively settle the identification issue, and in order to understand whether the emission lines observed in the optical spectrum are associated with the host or with the AGN activity, a deeper multiwavelength study is needed. This, however, is beyond the scope of this paper.

The nondetection of H_β emission does not allow us to estimate the internal reddening in the nucleus of NGC 4992. Therefore, we are not able to apply the diagnostics of Bassani et al. (1999) and of Panessa & Bassani (2002) to this case.

Under the hypothesis that the observed H_α emission is produced by the host galaxy and not by the AGN, we can use the flux of this line, corrected for Galactic absorption assuming a color excess $E(B-V) = 0.026$ mag (Schlegel et al. 1998), to estimate the star formation rate (SFR) in NGC 4992. From Kennicutt (1998), we determine a SFR of $0.025 \pm 0.008\ M_\odot\ \mathrm{yr}^{-1}$ from the reddening-corrected H_α luminosity of $(3.2 \pm 1.0) \times 10^{39}$ erg s^{-1}. This estimate should be considered a lower limit to the SFR as no correction for the reddening local to NGC 4992 was accounted for.

In conclusion, to the best of our knowledge, NGC 4992 is the first confirmed XBONG detected in hard X-rays with *INTEGRAL*, and the closest XBONG detected so far. Thus, it appears as an ideal laboratory for the study of this enigmatic class of galaxies.

4.6. IGR J20286+2544 (=MCG +04-48-002) and NGC 6921

The spectrum of the galaxy MCG +04-48-002 (Fig. 3, upper right panel) shows a number of narrow (again, with full width at half maximum of $\lesssim$600 km s^{-1}) emission features that can be readily identified with redshifted optical nebular lines. These include H_β, [O III] $\lambda\lambda$4958, 5007, H_α, [N II] $\lambda\lambda$6548, 6583, and [S II] $\lambda\lambda$6716, 6731. All identified emission lines yield a redshift of $z = 0.013 \pm 0.001$, in agreement with Paturel et al. (2003). The NaD doublet in absorption is also detected at the same redshift.

Concerning the spectrum of NGC 6921 (Fig. 3, lower left panel), we find it to be a typical spectrum of a normal spiral galaxy, with Ca H+K, G-band, H_β, Mg b, Fe I λ5270 and NaD in absorption, plus [N II] λ6583 and [S II] $\lambda\lambda$6716, 6731 in emission. All of these features are at a redshift of $z = 0.014 \pm 0.001$, fully consistent with that of Paturel et al. (2003). Given the substantially lower X-ray flux (as measured with XRT) from the nucleus of NGC 6921 with respect to that from MCG +04-48-002, we conclude that the actual optical counterpart of IGR J20286+2544 is the galaxy MCG +04-48-002, although we cannot exclude a marginal contribution from NGC 6921 to the total hard X-ray emission detected with ISGRI.

The diagnostics of Ho et al. (1993, 1997) seem to suggest that MCG +04-48-002 is a Starburst/H II galaxy: indeed, the line ratios [N II]/H_α, [S II]/H_α, and [O III]/H_β, together with the nondetection of [O I] λ6300 in emission (the 3σ upper limit to the flux of this line is 7×10^{-16} erg cm^{-2} s^{-1}), indicates that this galaxy falls in the Starburst/H II locus.

In spite of this, using the cosmology described above and the more accurate redshift of Paturel et al. (2003), we find that the luminosity distance to the galaxy MCG +04-48-002 is d_L = 66.2 Mpc, and that its 20–100 keV X-ray luminosity is 2.1×10^{43} erg s^{-1}. This value is very high for a Starburst (David et al. 1992), whereas it would be around average for a type 2 Seyfert galaxy (see, e.g., Beckmann et al. 2006). The measured value for the X-ray luminosity of MCG +04-48-002 is thus comparable with that of "classical" AGNs. Further, the detection of radio and hard X-ray emission and the *ROSAT* 0.1–2.4 keV nondetection suggest that this object is an obscured AGN.

This conclusion is further supported by the X-ray/FIR and [O III]/FIR flux ratios for this object: following the approach of Panessa & Bassani (2002), we find that its IRAS 25 μm + 60 μm flux, $F_\mathrm{FIR} = 6.9 \times 10^{-10}$ erg cm^{-2} s^{-1} (Sanders et al. 2003), its 2–10 keV flux (2.3×10^{-10} erg cm^{-2} s^{-1}; Landi et al., in preparation) and its unabsorbed [O III] λ5007 line flux (9.4×10^{-13} erg cm^{-2} s^{-1}; see below for the correction for internal absorption), place the nucleus of MCG +04-48-002 in the loci populated by Seyfert 2, rather than Starburst, galaxies (Figs. 2 and 3 of Panessa & Bassani 2002). In addition, the X-ray/[O III]$_{5007}$ ratio, ~2.5, indicates that this source is in the Compton-thick regime (see Bassani et al. 1999).

The strength of the optical emission lines of MCG +04-48-002, after accounting for Galactic and intrinsic absorptions, can be used to estimate the SFR and metallicity of this galaxy. First, a correction for Galactic reddening has been applied (we assumed a color excess $E(B-V) = 0.44$ mag following Schlegel et al. 1998). Next, considering an intrinsic Balmer decrement of $H_\alpha/H_\beta = 2.86$ (Osterbrock 1989) and the extinction law of Cardelli et al. (1989), the observed flux ratio $H_\alpha/H_\beta = 10.3$ implies an internal color excess $E(B-V) = 1.30$ mag (in the galaxy rest frame). Following Kennicutt (1998), we determine a SFR of $9.3 \pm 0.9\ M_\odot\ \mathrm{yr}^{-1}$ from the reddening-corrected H_α luminosity of $(1.18 \pm 0.06) \times 10^{42}$ erg s^{-1}.

Although the [O II] emission line, if present, falls outside the actual wavelength range covered by our Loiano spectra of MCG +04-48-002, the detection of [O III] and H_β allows us to infer a range for the gaseous oxygen abundance in this galaxy. Following Kobulnicky et al. (1999), the R_{23} parameter, defined as the ratio between [O II] + [O III] and H_β line fluxes, gives $7.0 < 12 + \log(\mathrm{O/H}) < 9.0$. Considering the intrinsic luminosity of the source (it has rest-frame absolute B-band magnitude $M_B = -21.36$ mag; Prugniel 2005) and its [O III]/[N II] ratio (~1.6), all of this information points to the fact that this galaxy is on the high-metallicity side of the range reported above, i.e., $12 + \log(\mathrm{O/H}) > 8.3$. We caution the reader that the [O III] and [N II] lines can be contaminated by AGN activity, so this may impact on the metalliticy lower limit derived above.

In conclusion, we put forward the hypothesis that this Starburst/H II galaxy, similarly to NGC 4945 (Lípari et al. 1997), hides an obscured Seyfert 2 nucleus, which can be seen only at hard X-rays and infrared/radio wavelengths. If this is true, this galaxy represents a further example of an optically elusive AGN, similar to NGC 4992 (see Sect. 4.5).

5. Conclusion

In our continuing work aimed at the identification of unknown *INTEGRAL* sources by means of optical spectroscopy (Papers I–III), we have identified and studied six more hard X-ray objects by using the Astronomical Observatory of Bologna in Loiano (Italy) and by reexamining spectroscopic data acquired at the 2.2 m ESO/MPG telescope in La Silla (Chile).

We determined the nature of the sources as follows: (i) IGR J00234+6141 is a CV, probably an IP, caught during a quiescent phase and located at $d \sim 300$ pc from Earth; (ii) IGR J01583+6713 is a transient Be/X HMXB located at ~6.4 kpc from Earth; (iii) IGR J03532−6829 (=PKS 0352−686) is a BL Lac at redshift $z = 0.087$; (iv) IGR 06074+2205 is likely a Be/X HMXB located at ~1 kpc from Earth, although soft X-ray observations should be made to provide a conclusive test on this identification; (v) IGR J13091+1137 is an XBONG probably hiding an absorbed

AGN, at redshift $z = 0.025$ and with $SFR \sim 0.03\ M_\odot\ \mathrm{yr}^{-1}$; (vi) IGR J20286 + 2544 (=MCG +04-48-002) is a Starburst/H II galaxy located at $z = 0.013$, with nearly solar metallicity and $SFR \sim 9\ M_\odot\ \mathrm{yr}^{-1}$, hiding an obscured type 2 Seyfert nucleus in the Compton-thick regime.

These results once more stress the importance of *INTEGRAL* for the detection and the study of hard X-ray emission not only from X-ray binaries, but also from CVs and extragalactic objects. Moreover, the findings presented here indicate that *INTEGRAL* is revealing a population of "buried" AGNs, the activity of which is hidden in the optical by local absorption and/or by the luminosity of their host galaxies.

Acknowledgements. We thank the anonymous referee for useful remarks which helped us to improve the paper. We also thank Stefano Bernabei, Ivan Bruni, Antonio De Blasi and Roberto Gualandi for the assistance at the telescope in Loiano and for having performed part of the observations in Loiano as a Service Mode run, and Jules Halpern and Retha Pretorius for comments and discussions. This research has made use of the NASA Astrophysics Data System Abstract Service, of the NASA/IPAC Extragalactic Database (NED), and of the NASA/IPAC Infrared Science Archive, which are operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This research has also made use of the SIMBAD database operated at CDS, Strasbourg, France, and of the HyperLeda catalogue operated at the Observatoire de Lyon, France. The authors acknowledge the ASI financial support via grant I/R/046/04.

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